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FAIREY, JOHN

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FARADAY, MICHAEL

FARADAY, MICHAEL (*b.* Newington Butts, Surrey [now London], England, 22 September 1791, *d.* Hampton Green Court, Middlesex, England, 25 August 1867), *electricity and magnetism, chemistry.* For the original article on Faraday see *DSB,* vol. 4.

Faraday's contributions to electricity and magnetism shaped nineteenth-century physics fundamentally, opened the possibility of a wider use of electric power, and laid the origin of field theory. Both for his contemporaries and for modern science studies, his experimental approach and unorthodox concepts have been challenging. At his time, his fame rested as much on his lecturing and counseling in public service as on his research.

Since the 1980s, Faraday studies have shifted their focus from Faraday's ideas, experimental discoveries, and intellectual influences toward the practice of his life, research, and religion. As a result, a new picture has emerged, and it has become clear that the degree to which Faraday's research was preshaped by philosophical ideas about the nature of matter and force had been considerably overestimated. This update article focuses on how his generation of knowledge—experimental, practical, conceptual, theoretical—was connected to, and shaped by, the other aspects of his life.

Working in the Royal Institution. Faraday's lifelong working site, the Royal Institution of Great Britain, had been founded in 1799 as a philanthropic initiative for improving the scientific education of craftsmen and practitioners, but quickly developed into a meeting point for the middle and upper class. Its finances depended largely on the income of the public lectures it offered, and hence on finding lecturers that attracted a substantial audience. In that respect, Faraday was as great a success as Humphry Davy had been before him. The Friday evening and the Christmas juvenile lecture series (founded in 1826 and 1827, respectively) were essentially his creation and much shaped by him.

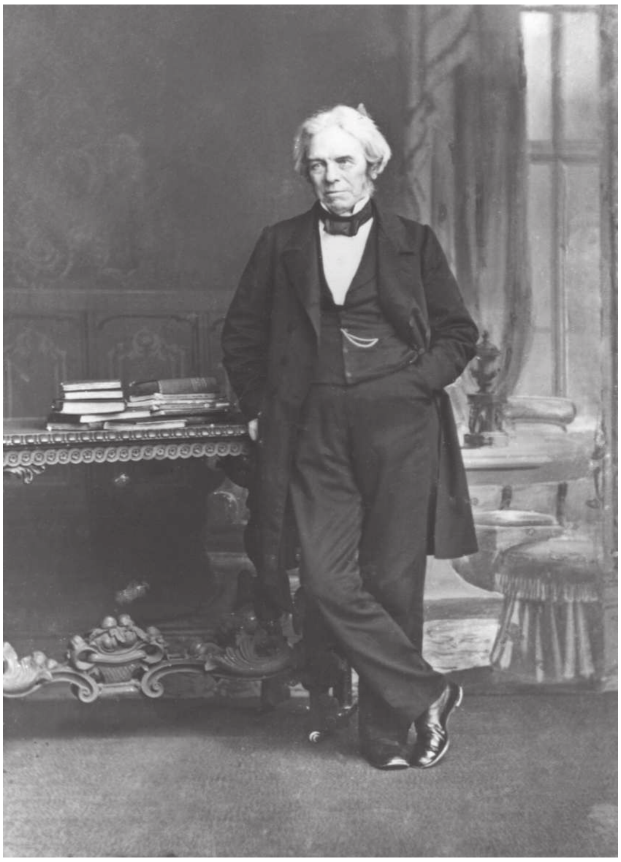
Pushed by Davy, and well beyond the needs of lecturing, the Royal Institution had installed a well-equipped laboratory and a library, in a period when the very idea of such laboratories was new and just starting to be realized. The Royal Institution's facility, well apt for cutting-edge research, developed into one of the best-equipped laboratories of the period, competing with places such as the Paris École Polytechnique. Faraday thus had unrestricted access to a unique resource of experimental research, a situation that he himself strongly endorsed and of which he took significant advantage. Both the lecture hall (where he spent much time) and the apartment he shared with his wife Sarah were in the Royal Institution's building, hence he could easily switch between work and home, research and lecturing, at least as long he was not interrupted by one of the many visitors calling for information. Of course, this was not a situation without tensions. Faraday's income at the Royal Institution was certainly not adequate, given the benefits he provided for the institution. However, he lived a modest life, even at the height of his fame, and gave the surplus mostly to charity. Nevertheless, his continued (and well-paid) teaching at the Royal Mili-

tary Academy at Woolwich for more than two decades was, among others, a deliberate step to lessen his financial dependence on one single institution with insecure financial standing. Moreover, combining living and work in one and the same house for a whole life was not necessarily a favorable arrangement. That Faraday was able to turn it into great success had also to do with the fact that his life had, besides work, also a second focus: his being part of the Sandemanian community—a life that took place outside the Royal Institution and in which, contrasted to his research and lecturing, Sarah took part equally.

To a far larger extent than hitherto realized, Faraday was active in public service. More than 10 percent of all of his correspondence deals with lighthouses alone, stemming from his work for Trinity House (from 1836 on). He was scientific adviser to the Admiralty, the Home Office, the Board of Trade, the Office of Woods and Forests, and the Board of Ordnance. These projects ranged from a gunpowder factory explosion to conservation issues of works of art. His inquiry into the devastating explosion at Haswell Colliery (1844) was a key event in the relationship of science and politics and in labor history—it is cited by Friedrich Engels for example.

The situation at the Royal Institution (which he himself had considerably shaped and stabilized), his enormous success as a public lecturer and scientific advisor, and his religious life combined to form a peculiar and very specific constellation—a constellation that gave him much inner and outer stability and relieved him to a considerable degree from the compulsion of scientific competition. This was an important element of his capacity to pursue his own ideas and conceptualizations, even through long periods of nonresponse or rejection from the academic environment.

Experimenting. Faraday is most known as an experimenter. Indeed, those achievements that made him famous in his time rely on experiments, be it electromagnetic rotation (1821), the liquefaction of gases (1823), the discovery of benzene (1825), electromagnetic induction (1831), the identity of various electricities (1833), the laws of electrolysis (1834), the magneto-optical effect (1845), or diamagnetism (1845–1846). Contrasting to the older picture of Faraday's experiments being guided by speculative views on matter and force, new studies of his experimental practice by David Gooding, Friedrich Steinle, and Ryan D. Tweney have drawn quite a different picture. The core of his experimental approach was never individual, single experiments but always extended experimental series—a point that is easily eclipsed when focusing on his prominent discoveries. But these discoveries are only understandable as outcomes of those experimental series. The main experimental procedure was a systematic



Michael Faraday. *Michael Faraday, circa 1865.* **HULTON ARCHIVE/GETTY IMAGES.**

variation of experimental parameters, with the goal of finding constant correlations and establishing laws. Explaining a specific effect meant to him, first of all, placing it in a wider surrounding of related effects, then "deducing" one from another by building a chain of experimental phenomena, or, as he said, "putting facts closely together." Sometimes this required framing new concepts, or transferring existing ones into a totally new context, as in the case of magnetic curves.

Faraday had a laboratory assistant, the former Sergeant Charles Anderson, but it seems that in his considerations about the meaning and ordering of experimental results, and the planning of further experiments, he worked essentially alone. When other scientists visited him in the laboratory, he would show them his ready results, but not discuss ongoing research—the same holds for his well-documented and extensive correspondence.

Faraday's experimental approach was intimately linked to his practice of record keeping. He probably put down notes right in the laboratory, but edited them in clear writing afterward (typically on a daily basis), numbered each entry for later reference, and eventually bound

these notes into books. In composing his papers for publication, he would often take directly the wording and the figures of his notebook. As the number of experiments increased greatly over the years, he started to work on indices and superindices to enable later retrieval. And even in later years he would still come back to experiments made more than a decade earlier. Such a conscious dealing with enormous amounts of experimental records was extraordinary at his time; see, for example, the contrasting case of Ampère.

Theorizing. Faraday's success as an experimentalist has long overshadowed his efforts and achievements in theorizing and conceptualizing. But his work was at least as strongly focused on understanding and ordering experimental outcomes as on obtaining new experimental effects. His approach focused more on formulating laws and on fundamental concepts than on searching for hidden entities that would provide causal explanations. More than others, he was ready to question fundamental concepts, such as electric current, electric attraction, and magnetic polarity, and to propose new concepts, such as electromagnetic rotation as an elementary effect, magnetic and electric curves (later to be renamed *lines of force*), specific capacity, dia- and paramagnetism, and of course electric and magnetic fields. In some cases he consulted other scholars (most notably William Whewell) for appropriate words in order to keep the new concepts as neutral as possible with respect to explanatory theories. Only when a firm experimental and conceptual foundation was achieved, was he ready to put real effort into the question of hidden causes, such as the theory of electrolysis or of polarization.

The concepts thus created were "empirically saturated," in the sense that Faraday formed and developed them with an ever-growing body of experimental results in mind, for which they should enable a formulation of regularities and laws. In face of new experimental evidence, he was ready to a very high degree to revise and refine those concepts again and again, with the result that in the end they found a very precise formulation, though not in mathematical language. That he was able to form such unconventional concepts at all had to do with his noncommitment to any established school of physical thinking, and with his deep feeling of the responsibility to fit his concepts to nature. At the same time, it was exactly this character of the concepts that made them appear weird for most of his contemporaries, because they did not resonate with the established body of knowledge of the period.

Ever since his first use of "magnetic curves" in 1831 for the induction law, he emphasized he was not claiming physical reality of these curves, but rather was using them

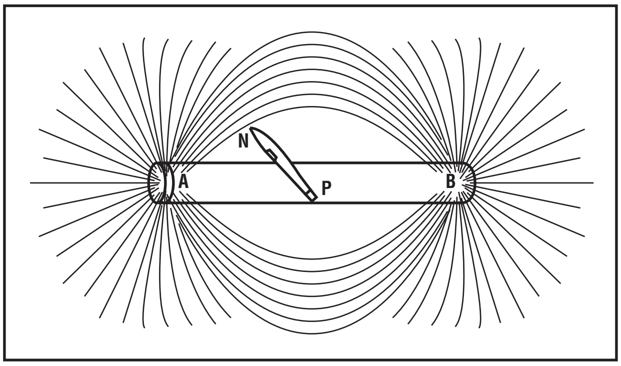


Figure 1. *To grasp the results of his numerous induction experiments (1831/32) in a law, Faraday used "magnetic curves" as a refererence frame. Despite his own success in formulating a law, the concept came to visibility only in the 1860s when Maxwell gave those "lines of force" a mathematical form.*

as a convenient tool to express the spatial distribution of magnetic force. Rather than being an "embarrassment" for Faraday, as Leslie Pearce Williams suggests in the original *DSB* article, this peculiar status of lines of force lay at the core of his approach. Faraday kept that cautious attitude for decades, even when conceiving the curves as movable (1832), introducing electric lines of force (1838), formulating diamagnetic behavior in terms of lines of force (1848), or finally developing a general theory of magnetism in terms of lines of force (1850). Only in 1851, at a stage when he oversaw a huge domain of electromagnetic effects, did he drop his reluctance and state that there probably was more to lines of force than just being descriptive tools: their successful application comprised much wider realms than any other concept of electrodynamics.

Religion. Throughout his life, and while living in the Royal Institution's building, Faraday kept apart his professional and private life. The latter was most intensely shaped by his adherence to the Sandemanian sect, a strict religious group that comprised not more than four hundred members in England and Scotland in his time. Faraday's confession of faith in 1821 was certainly one of the most important moments of his life. Like all members of that community, Faraday spent much time and effort with services, gatherings, and duties such as caring for the sick or preaching, often outside London. His important social connections were more or less completely located within the community and formed strong ties. It is indicative, for example, that while he generally refused to write support letters for anyone for positions, he deviated from this rule in the case of Sandemanian brethren. His funeral, on his own wish, and despite his wide fame, took place only within a small circle of Sandemanians.

Both his personal faith and the Sandemanian community life gave Faraday a considerable degree of personal stability. Correspondingly, however, instabilities within the Sandemanian community (such as his temporary exclusion in 1844) affected him profoundly and made him existentially suffer, in sharp contrast to problems and lack of resonance in his scientific surroundings. Moreover, his religion provided him with a specific attitude toward researching nature. In his 1854 lecture "Mental Education," he emphasized the importance of humility in the face of God's creation. The extraordinary degree to which he kept his concepts and theoretical ideas open for revision by further experience (dubbed "Negative capability" by Elspeth Crawford), and also his persistence in keeping his unconventional ideas, can well be understood as his own way of realizing that virtue.

Impact. Faraday's impact on research in electrodynamics (and physics in general) was immense. From 1830 on, he was the one to put challenges and create the "hot topics" in electrodynamics for two and a half decades: rotation, induction, specific capacity, magneto-optical effect, diamagnetism, and lines of force. The continuing series of Faraday's papers was translated into various languages on a regular basis. However, the reception was split in a characteristic way: While his experimental results were highly praised, his conceptual approach met with silence or criticism. This had partly to do with his total lack of mathematical education in a period when physics became strongly mathematized and partly with his uneasy way of presenting his results, switching between meticulous experimental descriptions and general considerations. The largest obstacle, however, was the unconventional character of some of his new concepts. Wilhelm Weber, for example, in his 1845 *Maassbestimmungen*, mentioned Faraday as a gifted experimentalist and discoverer of the induction effect, but found there was no law of induction. Obviously he did not regard Faraday's induction law of 1832 as something to be considered seriously—it was formulated in terms of magnetic curves and hence probably too far from anything a physicist of the time could deal with.

The second half of the century saw the development of field-theory in mathematical form. It is important to note that what James Clerk Maxwell set out to mathematize was not specific effects, domains, or laws, but the *concept* of lines of force, as he took it from Faraday. The striking historical observation that Maxwell's success in mathematizing the concept provided a comprehensive theory of a vast range of electrodynamic effects, without having discussed that variety of effects in detail, can be understood just by highlighting the "empirically saturated" and highly precise character of Faraday's concepts.

Faraday

A third aspect of Faraday's impact has received less attention. While Faraday never formulated anything like a methodology, his peculiar approach was quite visible and would eventually become subject of methodological considerations. The growing insight into the inadequacy of the search for the "hidden levers and screws" of nature during the last decades of the nineteenth century was in part stimulated by the complex dispute of Weberian, Neumannian, and Faraday-Maxwellian electrodynamics. A major exponent of that changing ideal of knowledge, Hermann von Helmholtz, explicitly attributed his own turn away from the search for hidden mechanisms to his reading of Faraday. Even in recent attempts to widen the understanding of experimental practice in general, Faraday figures as a prominent example and unique resource because of his peculiar productivity, the unique availability of sources that enable insight into his everyday practice, and the specific experimental approach that does not fit the standard view of experiment.

SUPPLEMENTARY BIBLIOGRAPHY

The Royal Institution of Great Britain, the Royal Society, the Guildhall Library, and the Institution of Engineering and Technology keep much archival material (manuscripts, lecture notes, and so forth), all of which has been microfilmed and stored on compact disc, available from Microform Academic, Wakefield, United Kingdom.

WORKS BY FARADAY

Faraday's Diary: Being the Various Philosophical Notes of Experimental Investigation Made by Michael Faraday during the Years 1820–1862 and Bequeathed by Him to the Royal Institution of Great Britain. Edited by Thomas Martin. London: G. Bell, 1932–1936.

Experimental Researches in Electricity. New York: Dover, 1965. Originally published 1839–1855.

Experimental Researches in Chemistry and Physics. London: Taylor & Francis, 1991. Originally published in 1859.

The Correspondence of Michael Faraday. 4 vols. Edited by Frank A. J. L. James. London: Institution of Electrical Engineers, 1991–. Complete edition, with excellent comments and introduction.

Curiosity Perfectly Satisfyed: Faraday's Travels in Europe 1813–1815. Edited by Brian Bowers and Lenore Symons. IEE History of Technology Series, 16. London: Peter Peregrinus, 1991. Faraday's notebook of the "Continental Tour."

Michael Faraday's "Chemical Notes, Hints, Suggestions and Objects of Pursuit" of 1822. Edited by Ryan D. Tweney and David Gooding. IEE History of Technology Series, 17. London: Peter Peregrinus, 1991.

OTHER SOURCES

Berman, Morris. *Social Change and Scientific Organization: The Royal Institution, 1799–1844.* Ithaca, NY: Cornell University Press, 1978.

Cantor, Geoffrey N. *Michael Faraday: Sandemanian and Scientist; A Study of Science and Religion in the Nineteenth Century*. Basingstoke, U.K.: Macmillan, 1991.

———. "The Scientist as Hero: Public Images of Michael Faraday." In *Telling Lives in Science: Essays on Scientific Biography*, edited by Michael Shortland and Richard Yeo. Cambridge, U.K.: Cambridge University Press, 1996.

Cantor, Geoffrey N., David Gooding, and Frank A. J. L. James. *Faraday*. London: Macmillan, 1991.

Caroe, Gwendy M. *The Royal Institution: An Informal History*. London: John Murray, 1985.

Cavicchi, Elizabeth. "Experimenting with Magnetism: Ways of Learning of Joann and Faraday." *American Journal of Physics* 65, no. 9 (1997): 867–882.

Crawford, Elspeth. "Learning from Experience." In *Faraday Rediscovered: Essays on the Life and Work of Michael Faraday, 1791–1867*, edited by David Gooding and Frank A. J. L. James. Basingstoke, U.K.: Macmillan; New York: Stockton, 1985.

Forgan, Sophie. "Faraday—From Servant to Savant: The Institutional Context." In *Faraday Rediscovered: Essays on the Life and Work of Michael Faraday, 1791–1867*, edited by David Gooding and Frank A. J. L. James. Basingstoke, U.K.: Macmillan; New York: Stockton, 1985.

Gooding, David. *Experiment and the Making of Meaning: Human Agency in Scientific Observation and Experiment*. Dordrecht: Kluwer, 1990.

——— and Frank A. J. L. James, eds. *Faraday Rediscovered: Essays on the Life and Work of Michael Faraday, 1791–1867*. Basingstoke, U.K.: Macmillan; New York: Stockton, 1985.

James, Frank A. J. L. "Michael Faraday and Lighthouses." In *The Golden Age: Essays in British Social and Economic History, 1850–1870*, edited by Ian Inkster with Colin Griffin, Jeff Hill, and Judith Rowbotham. Aldershot, U.K.: Ashgate, 2000.

———. "Running the Royal Institution: Faraday as an Administrator." In *The Common Purposes of Life: Science and Society at the Royal Institution of Great Britain*, edited by Frank A. J. L. James. Aldershot, U.K.: Ashgate, 2002.

——— and Margaret Ray. "Science in the Pits: Michael Faraday, Charles Lyell, and the Home Office Enquiry into the Explosion at Haswell Colliery, County Durham, in 1844." *History and Technology* 15 (1999): 213–231.

Nersessian, Nancy J. *Faraday to Einstein: Constructing Meaning in Scientific Theories*. Science and Philosophy. Dordrecht: Nijhoff, 1984.

Steinle, Friedrich. "Entering New Fields: Exploratory Uses of Experimentation." *Philosophy of Science* 64, Supplement (1997): S65–S74.

———. "The Practice of Studying Practice: Analyzing Research Records of Ampère and Faraday." In *Reworking the Bench: Research Notebooks in the History of Science*, edited by Frederic Lawrence Holmes, Jürgen Renn, and Hans-Jörg Rheinberger. Archimedes 7. Dordrecht: Kluwer, 2003.

———. *Explorative Experimente: Ampère, Faraday und die Ursprünge der Elektrodynamik*. Boethius 50. Stuttgart: Steiner, 2005.

Tweney, Ryan D. "Faraday's Notebooks: The Active Organization of Creative Science." *Physics Education* 26 (1991): 301–306.

———. "Discovering Discovery: How Faraday Found the First Metallic Colloid." *Perspectives on Science* 14, no. 1 (2006): 97–121.

Friedrich Steinle

FAREY, JOHN (*b.* Woburn, Bedfordshire, United Kingdom, 24 September 1766, *d.* London, United Kingdom, 6 January 1826), *geology, music, mathematics.* For the original article on Farey see *DSB*, vol. 4.

Farey has left a difficult legacy for those who follow him. First, he was a true polymath. His initial training was as a land surveyor. But from 1803, he pursued the entirely new profession of mineral surveyor (a term Farey invented in that decade). Farey also made significant contributions as an engineer, mathematician, musician, and geologist. Anyone trying to investigate him in the early twenty-first century should be impossibly as polymathic as he was; this has certainly not been the case in mathematics. Here, the famous, misinformed assessment of 1940, by the academic Godfrey Harold Hardy, was that "Farey is immortal [only] because he failed to understand a theorem which Haros had proved perfectly fourteen years before" (Hardy, 1940, pp. 21–22). Second, unlike Charles Darwin (to give only one famous example), Farey failed to leave any significant personal archives after his death, and thus all explorations of Farey's multiplicity of activities (and frustrations) have been made much more difficult. Another important consideration, within the worlds that Farey occupied, was that he was dependent on commissions. As he wrote in 1816, "my circumstances in life, and the state of the Times, less and less permit my indulging in any pursuits which do not make some return towards the support of my family. For several years past Mineral Surveying & Engineery have been my only dependance & source of Profit (except now and then writing a little for the periodical press and a trifle from the Smithfield Club)" (Farey, 1816). Farey had been appointed to the Smithfield Club in 1806, as paid secretary (£30 per year) and, from 1815, additionally as treasurer (£40 per year). He never enjoyed any regular salary or academic support.

Early Years and Interests. Farey was born on a farm of the fourth Duke of Bedford, tenanted by his parents, John Farey (1728–1798) and his second wife, Rachel Wright (1732–1804), who was a Wesleyan Methodist. After normal village schooling, Farey was sent in 1782 to the academy run by Robert Pullman in Halifax, Yorkshire. Farey